Psychological Research

Do experts see it in slow motion? Altered timing of action simulation uncovers domain-specific perceptual processing in expert athletes

--Manuscript Draft--

Manuscript Number:	PRPF-D-16-00074R1
Full Title:	Do experts see it in slow motion? Altered timing of action simulation uncovers domain-specific perceptual processing in expert athletes
Article Type:	Original Article
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Funding Information:	
Abstract:	Accurate encoding of the spatio-temporal properties of others' actions is essential for the successful implementation of daily activities and, even more, for successful sportive performance, given its role in movement coordination and action anticipation. Here we investigated whether athletes are provided with special perceptual processing of spatio-temporal properties of familiar sportive actions. Basketball and volleyball players and novices were presented with short video-clips of free basketball throws that were partially occluded ahead of realization and were asked to judge whether a subsequently presented pose was either taken from the same throw depicted in the occluded video (action identification task) or temporally congruent with the expected course of the action during the occlusion period (explicit timing task). Results showed that basketball players outperformed the other groups in detecting action compatibility when the pose depicted earlier or synchronous, but not later phases of the movement as compared to the natural course of the action during occlusion. No difference was obtained for explicit estimations of timing compatibility. This leads us to argue that the timing of simulated actions in the experts might be slower than that of perceived actions ("slow-motion" bias), allowing for more detailed representation of ongoing actions and refined prediction abilities.
Response to Reviewers:	Dear Dr Vicario, Thank you for the submission of your manuscript "Do experts see it in slow motion? Altered timing of action simulation uncovers domain-specific perceptual processing in expert athletes" to Psychological Research and for your patience in awaiting our decision. I was waiting for one more review, but today decided that I could work with what I hold in hands because we have received the reports from two advisers on your manuscript. Based on the advice received and my own reading of your manuscript, I feel that your manuscript could be reconsidered for publication should you be prepared to incorporate major revisions. YOU ARE KINDLY REQUESTED TO ALSO CHECK THE

WEBSITE FOR POSSIBLE REVIEWER ATTACHMENTS!

In additon to the comments of the reviewers, you should also please the following conerns that I had when reading your manuscript:

1. p. 4. What is a "pavement phase"?

We are sorry for this misspelling. We meant “movement phase”.

2. If I understood the methods correctly, correct synchronous poses were by far less frequent than incorrect ones. Earlier and later poses were two times as likely as synchronous poses. Were the participants informed about this? Why was this done? How could this have affected the performance?

In the implicit task, we had a comparable number of earlier, synchronous or later poses. However, please note that the temporal manipulation here was completely task irrelevant, since participants should just identify if the test pose was taken from the same or different throws as compared to the interrupted video clips. Half of the trials were same and half were different, thus preventing any bias in participants’ responses. Conversely, the explicit temporal task did not include any synchronous trials, in keeping with relevant research on temporal estimation tasks that present various levels of asynchrony but do not include synchronous trials. The PSE is indeed estimated by the responses on asynchronous trials (see line 242). We have now clarified this issue in the text.

3. I did not understand why your kinematic-identity discrimination task required the combination of early and later and synchronous poses? Is this a "standard task" used in past research for which you want to find out if temporal discrimination abilities contributed to performance in it? If yes, please note that this does not get across very clearly. If not, please justify what you are doing.

The paradigm adopted in the implicit task was taken from the occluder paradigm, which we discuss in the introduction section. Indeed, in this task, the manipulation of temporal congruency is orthogonal to the task at hand (e.g., discriminating if the test pose was taken from the same throw of the interrupted video clip), but it still affects performance. This way, it provides an implicit measure of the temporal properties of the simulation processes used to match the stimuli. We have tried to further clarify this issue in the introduction and through the text..

4. I did not understand how d' was calculated. E.g., What counted as a hit? What counted as a false alarm? (See also comment of reviewer 1.)

#We used a standard adaptation of the SDT to 2-alternative forced choice task (Macmillan & Kaplan, 1985). In the d′ analysis, same trials dentified as same were considered as “hits” and different trials identified as same were considered as “false alarms.” The d′ values were calculated by transforming the response proportion to z-scores, and then subtracting the z-score corresponding to the hit rate from the z-score corresponding to the false-alarm rate (Stanislaw and Todorov, 1999). Furthermore, we calculated, for each subject and condition, a measure of response criterion (c), which reflects the existence of a bias in providing a specific response. The c values were calculated by averaging the z-score corresponding to the hit rate and the z-score corresponding to the false alarm rate, and then multiplying the result by -0.5 (Stanislaw and Todorov, 1999). Please refer to lines 248-259

Reviewer #1:
The main aim of the article is to understand the influence of the spatial and temporal components in action recognition and to unravel whether the level of skills that a person has with respect to the action observed is related to the level of accuracy in the specific action recognition.
The article is interesting but strangely does not take into account a relevant related literature dealing with the so-called representational momentum RM (Freyd & Finke,

1984) or "forward displacement" FD (for review, see Hubbard, 2005, 2006; Kerzel, 2006). The paradigm applied is similar to the one applied for detecting RM and the main point is that RM effect predicts different time evaluation hypothesis when considering the error in time estimation or when considering the role in time estimation played by experts.

We thank the reviewer for this suggestion. We have now mentioned this similarity between our task and the RM and we have added the relevant references in the text. Please refer to lines 58-71.
We acknowledge that the findings of RM experiments would predict an anticipatory bias in this task and this was, indeed, our hypothesis. However, this anticipatory bias has never been observed in the occluder paradigm or when participants were explicitly asked to predict the future position of a moving object. In fact, these studies have shown, similarly to the present findings, a delay, rather than an anticipation bias, which has been attributed to the shift from a perceptual to a simulation-based processing of actions. As further clarified in the text, the specific task requested (e.g., explicit temporal discrimination task, memory for trajectory points or spatial kinematics discrimination task) and the type of actions may heavily influence the findings. Nevertheless, our aim was to compare expert and non experts on the same task, thus highlighting the perceptual correlates of domain specific expertise.

Literature has been shown that action recognition in the space-time domain is affected by the represented sequence velocity (e.g., Hubbard, 1995; Munger & Owens, 2004), in this study velocity is not considered as having influence. Importantly in this type of paradigm it has been observed along with the effects of the observer's prior implicit knowledge, some important effects due to principles of physics such as gravity (Hubbard, 1995, 1997; Hubbard & Bharucha, 1988). Indeed, the memory for the vanishing location of a horizontally moving target is usually displaced forward in the direction of motion (RM), and downward in the direction of gravity (RG, representational gravity). In other words, descending targets produce larger displacements in the direction of motion than ascending ones do (Hubbard, 1990, 2001; Hubbard & Bharucha, 1988). Moreover, this downward displacement has been shown to increase over time (see Hubbard, 2005). In this study showing the body displacement or the trajectory of the ball include gravity but in a very different way. Please answer to this issue and explain why these aspects are not considered as relevant.

We thank the reviewer for this comment. We do agree about the relevance of all the above mentioned variables in the temporal representation of the body action and ball motion sequence. However, we did not manipulate or control specifically for these variables, as the specific goal of the current research was focusing on the influence of action familiarity and motor expertise in the implicit vs. explicit time processing. More specifically, considering the ball trajectory, videos were interrupted during the upward phase and thus participants had to simulate both the last part of the ascending phase and, for the longest Occlusion/interruption times, the initial part of the downward trajectory. We have now clarified this on p. 7, lines 204-209. We have also acknowledge the role of these variables in relation to our experimental paradigm in the introduction and discussion sections (pp. 58-71; 176-180; 443-456;)

I think that this work needs to be more specific and precise in declaring exactly which part of the videos was actually visible for both body sequence and ball trajectory. Was the trajectory visible before reaching the zenith? Was it instead after that point? What was the rational behind the definition of the time of occlusion and the interruption time?

To address this reviewer's comment on the stimuli as well as reviewer 2's comment on Fig. 1, we have now modified our figure 1 in order to provide a more clear description of the experimental stimuli. In particular, we now show the frames that show the critical movement phases at which videos could be interrupted (i.e. either at 300 or 500 ms after video onset), and the possible test poses (i.e. either 100, 300, 500 after the interruption time). As clarified above, videos were interrupted during the ascending phase of the ball trajectory, and the occluded actions could include both the ascending and descending phase. The selection of the interruption and occlusion time was simply based on the need to variegate the duration of the videos before occlusion

and to manipulate the occlusion time so that it did not exceed video duration even at the longest condition given by the 500 ms interruption time and 500 ms occlusion time. We have now specified this in the MS text (p. 6)

Why you decided not to consider volleyball video-clips as additional condition? This condition will help the understanding for the specificity in action-recognition, unfortunately right now according to the data presented remains an open question.

We do agree with the reviewer that volleyball video-clips as an additional condition would had provided further evidence in favor of the domain-specificity of the findings. Unfortunately, considerations of the total time required to perform the task and of the time availability of the participants prevented us from adding further conditions to the experimental design. We thus chose to test a further group of participants (volleyball players) in order to rule out that the effects were overall related to sport performance. We agree, however, that documenting a double-dissociation between the two sports would have provided more convincing support that the effects are not specifically related to basketball videos, thus, we have now discussed this missing condition as a limitation of the current work and as a potential condition to test in future works (lines 491-493).

Moreover, novices in some cases performed better than volleyball athletes… why is that?

Although Figure 1 seems to show higher d-prime scores for novices compared to volleyball players, this difference never reached the statistical significance. Thus, we did not provide discussion on this point.

Please consider as well that SOA might have influences in sequence recognition based on the gravity involved, the velocity of the ball and the level of experience of the observer (Blattler et al 2010, 2011).

As already discussed above, we do agree with the reviewer about the potential influence of the mentioned variables to participants' performance, especially for the videos showing the ball trajectory. The level of experience of the observer has been already addressed (i.e., the participants' familiarity with the presented stimuli), as it was one of the main research goals of our study (for instance please see lines 179 and 147-148; 347-348; 423-432). On the other hand, we did not discuss the role of gravity and velocity, as these variables were not the object of our research and therefore were not manipulated across the groups and the experimental conditions. We have acknowledged, however, in the discussion that previous studies (Blättler et al., 2010; 2011- lines 67-69; 464-470) have found expertise effects for the representational momentum for moving stimuli.

The way d-prime is explained needs a reformulation to make it clearer.

We have now reworked this part of the text to make it clearer. Please refer to lines 248-259. We now say: Considering that in two-alternative-forced-choice tasks, like the one in the present study, it is possible that accuracy percentage conflates bias with decision, we used a standard adaptation of the SDT to 2-alternative forced choice tasks (Macmillan & Kaplan, 1985). Thus, we calculated and analysed d' prime and criterion (c) by plotting the proportion of same responses in same and different trials. The d' prime and lnβ scores were then calculated, considering as "hits" same responses for the same trials and as "false alarms" same responses for the different trials. The d′ values were calculated by transforming the response proportion to z-scores, and then subtracting the z-score corresponding to the hit rate from the z-score corresponding to the false-alarm rate (Stanislaw and Todorov, 1999). Hence, the higher the d-prime score, the better participants were able to detect a discrepancy in the kinematic patterns of the different test pose sequences. Furthermore, we calculated, for each subject and condition, a measure of response criterion (c), which reflects the existence of a bias in providing a specific response. The c values were calculated by averaging the z-score corresponding to the hit rate and the z-score corresponding to the false alarm rate, and then multiplying the result by -0.5 (Stanislaw and Todorov, 1999).

Reviewer #2: Comments to the Author

In the present MS, Vicario and colleagues investigated the influence of domain-specific motor expertise for the perceptual processing of spatio-temporal properties of sport actions. Basketball players, volleyball players, and novices were presented with video clips of basketball free throws. These throws were cut into video scenes ending either ahead of realization (i.e. before the ball left the players hands) or beginning briefly after realization of the throw (i.e. ball flight trajectory). The occluder paradigm was used to investigate whether presented test poses of video-clips were either taken from the same throw depicted in the occluded video (action identification task) or whether the test pose was temporally congruent/incongruent with the expected course of the action during the occlusion period (explicit timing task). Results showed that basketball players outperformed novices and volleyball players in detecting action compatibility when the test pose depicted earlier, but not later phases of the movement as compared to the natural course of the action during occlusion. Basketball players outperformed only volleyball players, but not novices in detecting action compatibility when the test pose depicted earlier phases of the movement. The authors argue for a slow-motion bias, that is, for a slower action simulation than action perception process. Regarding the explicit timing task, no difference was found between groups.
The study is very interesting and the paradigm is generally well designed. I guess, however, that the introduction of the MS needs some more specific empirical and theoretical references to the literature of action simulation (see below). I also think that the results are quite interesting, but I have some concerns (detailed below) regarding the presentation of the results and its discussion.

We are grateful to the reviewer for her/his positive comment to our work.

Introduction:
The main goal of the present study is to draw conclusions about the timing of simulated actions in dependence of domain-specific expertise. Some empirical work referred to in the introduction (e.g. Haggard et al., 2002), in my opinion, is rather unspecific for the investigated issue of the presented study. It might help the reader to capture the topic if some more empirical work about the duration/timing of mentally simulated actions is discussed (e.g. Guillot et al., 2005; or is at least presented in more detail; e.g. Graf et al., 2007; Prinz et al., 2008). I think this is both relevant for the action identification task and for the explicit timing task.

We thank the reviewer for this suggestion. We have now reworked the introduction by focusing on more relevant literature as suggested by the reviewer. Please refer to page lines 39-48. We also expanded the introduction by including the relevant literature on “representational momentum”, as suggested by the reviewer 1 (lines 58-71).

Moreover, I suggest that you should say some more words about action simulation theory and relate it to the empirical work on the timing of mentally simulated actions and the empirical work on experts' action anticipation superiority (your second section in the introduction).

We believe we have now addressed this point in the introduction. Please refer to lines 39-48.

Minor: Line 88, parenthesis (2011 needs to be deleted

We have now deleted the parenthesis, thank you.

Minor: Line 99, I am sorry, but I don' t understand the meaning of "pavement" phase?

We are sorry for this error; we meant movement phase.

Minor: Line 111, not athletes or non-athletes?

We thank the reviewer for this further suggestion. We have now changed the term

	"not athletes" with the term "non-athletes" Last section of the Introduction: lines 114-119, I miss hypotheses about the timing aspects of the tasks. # We thank the reviewer for this further suggestion. We have now tried to clarify this part in the text (line 113-123). Please argue why athletes are expected not to outperform novices in predicting the ball flight trajectory. One could imagine that basketball players have extensive visual expertise for ball flight trajectories. Or is it rather a general, sport-unspecific expertise to predict physical parameters of curves… # Our outperformance prediction was only formulated for body kinematics, given the evidence (e.g., Abernethy et al., 2008; Makris & Urgesi, 2015; Urgesi et al., 2012) of superior ability of athletes to perceive body kinematics and simulate observed actions in sport sequences that they are familiar with. Nevertheless, we agree with the reviewer that an outperformance concerning the ball flight trajectory was a plausible prediction, according to her/his suggestion (i.e., extensive visual expertise for ball flight trajectories and/or sport-unspecific expertise to predict physical parameters of curves). We have now reworked this text section by including the possibility to detect an outperformance also for the ball flight trajectory. Please refer to lines 121-123. Materials and methods: Please provide information about the mean training experience (years of training) of the basketball player and the volleyball player group. # Basketball players had 12.2 years (SD=1.9) of experience playing basketball and volleyball players had 12.1 years (SD=3.7) of experience playing volleyball, with no difference between the two groups [t(38)=0.11, p=0.915]. Novices had no experience playing any sport. See p. 5). Line 128-130, "Only female observers were tested in order (…) and to facilitate the involvement of simulation processes". I don't understand this sentence. Is this statement related to a match between the observing participants and the stimulus model? If so, then state it explicitly, please. # The model used in the videos was female. For this reason, we decided to test only female participants, as the gender match between the observer and the model was supposed to facilitate the involvement of simulation processes. We have now clarified this in the text, lines 132-134. Stimuli and apparatus: Please give some information about the difference between the videos A and B. Apparently, the ball trajectory differs. But can you say something about differences between A and B evident in body kinematics? # We thank the reviewer fro prompting us to further clarify this issue. We have now adapted figure 1 to provide a more precise representation of the differences between the two actions, either in body kinematics and ball trajectory. As now described in the text (and depicted in figure 1, throw B was characterized, as compared top throw A, by a more parabolic trajectory of the ball, which was induced by pushing the ball more on the vertical axis than on the horizontal axis. The corresponding kinematics differences were related to more flexed elbow, shoulder and wrist articulation during the initial and intermediate phases of throw B as compared to throw A (see p. 6). Please check the presentation of the numbers (e.g. 2,000-ms, 1650 ms, 1100ms) # We thank the reviewer for this suggestion. We have now made the text consistent according to APA style. Figure 1 I guess the grid at the video frames could be deleted. Instead, say something in the figure caption about differences between A and B.

We have now modified Figure 1 and describe the differences between the two throws in the text.

Task 1: Identification task
Line 160-161; basketball players instead of basket players.

Done.

Line 162: ball-trajectories instead of ball-trajectory (?)

Done

Please refer to Table 1 within the text. Maybe you could think about adding the SOAs in Table 1.

Done.

Figure 2: A small table might suffice to illustrate the video-combinations.

Done

Table 2: Congruent and incongruent combinations of the two types of video-clips.

CombinationSTART SHOOTINGOCCLUSIONTEST POSE
Congruent (same)VIDEO AVariable durationVIDEO A
Congruent (same)VIDEO BVariable durationVIDEO B
Incongruent (different)VIDEO AVariable durationVIDEO B
Incongruent (different)VIDEO BVariable durationVIDEO A

Task 2: Explicit timing task
Why didn't you measure accuracy rates for the pose-time = occlusion time condition?

With respect to the explicit timing task we only calculated the PSE as this is the standard procedure expected for such type of task (e.g., see Edward A. Wasserman, Thomas R. Zentall, Oxford University Press, 2006), as participants were asked to provide response in the context of two alternative forced choice.

Line 202-205, Something is wrong in this long sentence, I guess.

We have now revised the sentence.

Results:
Task 1: Identification task:
You calculated d prime and the criterion. I think it would be appropriate to briefly refer to the signal detection theory. Moreover, you should state for the reader, who are unfamiliar with SDT, what the d-values and the criterion-values mean. For example, the higher the d-value, the better the discrimination between same/different video - test pose sequences…. The criterion is a likelihood-ratio… a response bias is indicated by values …

We thank the reviewer for this comment. We have now added a description of the SDT and relative measures in the text (lines 249-259).

I would also like to see the accuracy rates for the different conditions. Maybe you can add the mean accuracy rates and SE in Table 2 for each condition below the d-prime values.

We thank the reviewer for this suggestion. Considering that d prime values were already shown in Figure 3 and in text, we elected to include in Table 2 (now table 3) only the mean accuracy values, in order to avoid redundancy of data presentation. Furthermore, this way we have also included in the same Table the Accuracy level for

the Explicit task, thus addressing the below issue about the comparability of the results. As discussed below, the two tasks were very different and required different processing and differential manipulation of spatial and temporal congruency between the test pose and occluded videos. Thus, we could not analyse them using the same design. However, showing the accuracy values for both tasks in Table 3 seems a more neutral way to present data and allow the reader to compare performance in the two tasks for descriptive purposes.

Regarding the d prime post-hoc comparisons following the cue type*SOA*group-interaction, I wonder why you did not analyse whether or not d-prime values differ for the different SOAs within each group. Nevertheless, you argue that earlier SOAs led to better performance than later SOAs in all groups (discussion section, line 303-304). Regarding the descriptive data, this statement might be true, however, I think you should compare the d prime values between SOAs statistically.
Moreover, I guess you need to analyse whether or not the d prime values differ significantly from 0. If the d prime values do not differ from 0, participants' discrimination ability is at chance level.

We have now provided these further results (see p. 11). The d' of all groups was significantly higher than 0 in all groups except for the later SOAs in basketball and volleyball players.

Task 2: Explicit timing task
I am not an expert in the application of psychophysical analyses, so it might be possible that I understand something wrong here. First: I do not understand why the SOA = 0 condition was skipped. The "too far forward responses" should be 50% in this condition (for a real time-simulation), or even more than 50% (for a slow motion simulation). Or am I completely wrong here? Second: I would also expect psychometric curves if psychophysic analyses were conducted.
You should explain the meaning of the PSE -values and its interpretation.
I would also like to see accuracy rates for the explicit timing task.

We thank the reviewer for this further comment. We did not include the SOA=0 in the analysis in order to avoid inducing bias in participants' response since the task required a binary response (i.e., Participants were asked to establish whether the actions presented after the temporal occlusion had been taken too far forward or too far backwards in time, in relation to the duration of the temporal occluder). By excluding the SOA=0 condition, the proportion of stimulus conditions far forward and far backwards in time are fifty-fifty. This has been done in keeping with previous studies using this type of task.
The reviewer is right that the PSE is extracted from psychometric function fitting, but these are not necessary for understanding the meaning of the overall PSE results. In this specific case we elected not to plot the curves to avoid confusions related to the low number of observation (SOAs) we took. We have however provided more information regarding PSE and its meaning in the text (lines 314-317). Furthermore, we now show accuracy rates for the early and later SOAs in Table 3.

Within the whole section: basketball players instead of basket players; volleyball players instead of volley players.

Done, thank you.

Besides, is there any reason why you conducted different statistical analyses for the two tasks? I guess the results of task 1 and 2 could be better compared if identical analyses would be applied.

For each task, we conducted the more appropriate analyses according to what is suggested in the literature. In the first task (i.e., identification task), participants had to indicate whether the pose presented after the occlusion belonged to the same or different action sequence. Thus, participants were asked to detect a discrepancy in the kinematics patterns of the presented visual stimuli. As such, this is purely a detection two alternative forced choice task, for which the signal detection analysis is the most appropriate one. Please refer to the main text lines 248-259 for more details.

For the second task (explicit timing task), participants had to actually make a explicit time comparison between a reference and a test duration (i.e., establish whether the presented actions had been taken too far forward or too far backwards in time, in relation to the duration of the temporal occluder). Accordingly, the most appropriate analysis is the calculation of the Point of Subjective Equality, which allows identify at what point the difference between two durations is detectable. At the point of subjective equality (PSE), the subject perceives the two weights to be the same. We have now added these explanations in the text. Please refer to lines 314-317.
Please also note, as explained in the text, that temporal manipulation was independent to subjects' response in task 1, and could be entered as independent variable in the analysis of the same-different responses. In contrast, the temporal manipulation was related to task performance in task 2 and we could not treat it as independent variable. Thus, we needed to analyse the results of the two tasks independently for their intrinsic properties.

Discussion
Line 299-301, you argue for a better performance in basketball athletes compared to volleyball athletes and novices in the identification task for sync. SOAs. However, in the result section (line 137) the comparison between basketball players and novices did not reach significance. Please correct.

We are grateful to the reviewer for this note. We have now correct the sentence according to the detected results.

Line 303-306: See last comment in the result section/task 1…

We have now compared data across SOAs and found significant differences in all groups, even if stronger and more reliable in the expert group.

Your discussion about the alternative explanation for the results in the identification task is very important. And, to be honest, I rather think that your alternative explanation might better explain your results than your "slow-motion action-simulation hypothesis". For me, it seems not to be very plausible that a slow-motion simulation is helpful for action prediction in sport settings. I mean, precise predictions are very important. But more important in fast running sport actions, action predictions have to be in time. Therefore, I would rather think of a kind of extrapolation of future events instead of a delayed simulation, or at least a real time simulation, as commonly claimed.

We thank the reviewer for prompting us to further discuss the significance of our interpretation in the light of the present data and previous studies. As we now discuss, this delayed extrapolation of future events has been shown fort the motion of common objects and interpreted either cognitively (i.e., load of the representation) or functionally (i.e.; being ready to change reactive behavior in the case the opponents change their behavior). Even if we admit that going too much deeper into this issue would make the discussion a bit more speculative, we have tried to consider previous studies on this issue and to give a more coherent presentation of our results in the context of previous literature.

Another alternative explanation to the "slow-motion action-simulation hypothesis" might be that action simulation generally involves a constant time error (and the action simulation is in real time).
You might consider this issue in the discussion.

We acknowledge the point raised by the reviewer, and indeed we discuss the finding of a constant lag explained by the shift from perceptual to simulation processes in the MS text (lines 412-421).

To further illuminate whether or not there is a bias for lower pose times, you could have a look at the 300 ms poses separately for early, sync., and late pose times, as you have all SOAs for the same test pose in the discussion.

We agree with the reviewer that seeing how the occlusion time affects the performance, independently from the test pose used, would be a good test for controlling for the constant time error interpretation (see Sparenberg et al., 2012).

	Unfortunately, since the present study was specifically design to investigate the presence of a constant error, limiting the analysis to the 300 ms pose would not leave enough power for the test. Furthermore, since variable pose times were presented in the task, extrapolation of only some cell would bias the results. Thus, we have elected not to perform this analysis. However, we have conducted a control analysis comparing occlusion times while collapsing across pose times and found that performance tended indeed to decrease with longer occlude times. However, since the test poses were not evenly represented in the different occluder times, the results of this analysis are ambiguous and we are not reporting them. Nevertheless, we have now extended our discussion about the possibility that the data reflects a constant time error and acknowledge that further research controlling specifically for different occlusion times at the same post time might allow clarifying the effects (see lines 413-421). Line 342,"(…), suggesting that their (the experts') action simulation processes were even slower than those of non-experts". I don't understand this conclusion. Please explain. # We have now rephrased the paragraph to clarify our point. Did you instruct participants to mentally simulate the perceived action after video offset? Or did you ask participants after the experiment about strategies when solving the tasks? Maybe you suggest that the observed action is automatically simulated after video offset. Maybe you can add some information about this issue. # We did not instruct participants nor collect any subjective measure about the strategy used. We have now clarified this issue in the methods section (221-222) Line 326, test pose, instead of pose test. # Done, thank you. Generally: I would like to see a better integration of the results into a theoretical framing of action simulation theories and not only a comparison with empirical work. # We hope that the many changes performed in the discussion section have helped to improve the discussion of the theoretical impact of our results. We have tried to be cautious, however, in drawing any conclusions, since further data are required to corroborate the finding.

Do experts see it in slow motion? Altered timing of action simulation uncovers domain-specific perceptual processing in expert athletes

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Abstract

Accurate encoding of the spatio-temporal properties of others' actions is essential for the successful implementation of daily activities and, even more, for successful sportive performance, given its role in movement coordination and action anticipation. Here we investigated whether athletes are provided with special perceptual processing of spatio-temporal properties of familiar sportive actions. Basketball and volleyball players and novices were presented with short video-clips of free basketball throws that were partially occluded ahead of realization and were asked to judge whether a subsequently presented pose was either taken from the same throw depicted in the occluded video (action identification task) or temporally congruent with the expected course of the action during the occlusion period (explicit timing task). Results showed that basketball players outperformed the other groups in detecting action compatibility when the pose depicted earlier or synchronous, but not later phases of the movement as compared to the natural course of the action during occlusion. No difference was obtained for explicit estimations of timing compatibility. This leads us to argue that the timing of simulated actions in the experts might be slower than that of perceived actions ("slow-motion" bias), allowing for more detailed representation of ongoing actions and refined prediction abilities.

Timing skills in expert athletes

Key words: Sport excellence**,** action simulation, action compatibility, body kinematics, temporal prediction, time.

Introduction

Accurate temporal estimations are essential to face the surrounding variety of everyday situations (Vicario et al., 2013). Gestures of our daily life, however simple or complex they are, always require precise time keeping. This appears to be particularly important for sportive competition, given the key role of action anticipation, motor coordination and motor synchronization for a successful sportive performance. The study by Chen et al. (2014) provides support to this view, documenting higher accuracy and lower variability in elite fencers asked to reproduce the duration of an image of scrambled pixels. This study suggests that elite athletes may be equipped with a superior ability in detecting the duration of visual stimuli, which might be related to their long-term sport training.

The research on mental imagery (MI) provides further insights to understand the role of timing skills in sportive performance. MI has been defined as mental representation of movement with no concomitant production of muscular activity to implement the movement (Denis, Chevalier, & Eloi, 1985. See also Guillot & Collet, 2005 for a review). In the study by Barr & Hall (1992), MI duration and the actual movement duration were found to be similar in top elite rowers, indicating a relationship between expertise level and MI. In similar fashion, McIntyre and Moran (1996) reported that MI duration of a slalom course was similar to the actual paddling times in a canoe–kayak competition. Durations of MI and actual action (500-m skating sprint) were shown by Oishi, Kasai, & Maeshima (2000) to be very close to each participant’s personal-best performance (from 35–38 s). In those studies, athletes were instructed to imagine that they were in an actual competition. The trials, and a correlation was established between the difficulty of imagining the task and the subjective sensation of effort.

Here we provide new insights in the field by testing a group of professional basketball players presented with a set of familiar sportive actions. Extensive research has shown that athletes possess a unique ability to perceive body kinematics and simulate observed actions in sport sequences that they are familiar with (Abernethy et al., 2008; Aglioti et al., 2008; Makris & Urgesi, 2015; Tomeo et al., 2013; Urgesi et al., 2012). In such experiments, professional athletes were presented with a sport action sequence (i.e., penalty kicks) interrupted at a critical point and they were asked to predict the outcome of the observed action. Results have shown that the bigger the athletes’ familiarity with the observed actions, the better their performance in predicting the action outcome. This phenomenon might be due to the superior abilities of experts to mentally simulate observed familiar actions and to form anticipatory representations of not visible or not yet happened actions.

Evidence supporting the role of expertise in anticipatory representation of movements comes from behavioral studies showing the so-called *representational momentum* effect, in which the memory for the final position or configuration of a moving object is distorted forward along its path of motion (Freyd, 1983; Freyd & Finke, 1984; Hubbard, 2005; Kerzel, 2006). This effect has been demonstrated with a variety of stimuli, including common objects (Finke & Shyi, 1988) and human figures (Verfaillie & Daems, 2002). The anticipatory representation of motion documented by the representational momentum paradigm demonstrates the ability of the visual system to use internal models of the physical rules that govern object motion in the environment, for example velocity (Munger & Owens, 2004) and gravity (Hubbard, 2005; Motes et al., 2008; Zago & Lacquaniti, 2005), in order to bridge discontinuities in visual inputs and to compensate for the intrinsic delay between the timing of perceptual processing and that required for planning and executing appropriate motor responses (Hubbard et al., 2005). Indeed, the observers' expertise with the moving scene (e.g., road or landing scenes) influences the presence and/or amount of representational momentum (Blättler et al., 2010; 2011). Importantly, the perception of movements performed by conspecifics may also rely on motor simulation processes, which use the motor representations established during planning and execution of one's own actions (Flach et al., 2004; Ramnani & Miall, 2004; Urgesi et al., 2010; Verfaillie & Daems, 2002).

A paradigm that has been used tot test these simulation processes is the so-called *occluder paradigm*, first developed by Graf et al. (2007), in which participants view action displays that are occluded after a variable delay and immediately followed by the presentation of a test pose that represented a spatially and/or temporally coherent or incoherent continuation of the previous action sequence. In typical implementations of this paradigm, the observers have to indicate (i.e., action discrimination task) if the re-appearing action part (after occlusion) is an accurate continuation of the perceived action (seen prior to occlusion), or if it has changed in spatial properties independently from the temporal coherence of action continuation after the occlusion (Springer et al., 2011), or has jumped in time even if the spatial properties of the movements are coherent (e.g., Stadler et al., 2011). Using different sets of everyday action stimuli (for a review see Springer et al., 2013) it has been shown that the higher the temporal congruence, the better the ability to match the movement kinematics of the test pose with that of the action shown before occlusion. This phenomenon takes place even if the participants have to disregard the temporal congruence between the duration of the occlusion and the phase shown in the test pose. This is considered to reflect the use of online simulation of the ongoing action during the occlusion, which leads to better performance when the state of the action simulation process corresponds with the timing of the reappearing external action. Thus, this paradigm is optimal for studying the timing of the internal representation (simulation) of the occluded action part. Interestingly, previous studies in non-sportive individuals have shown comparable reduction of kinematics matching accuracy when the test pose was either anticipated or delayed as compared to the time course of the occluded action, suggesting a correspondence between simulated and external actions (Springer et al., 2013). However, since motor expertise may affect time perception (e.g., Nather et al.,2011; Chen et al., 2014) and since elite athletes show superior perceptual abilities in predicting the outcome of familiar actions ahead of realization (Abernethy et al., 2008; Aglioti et al., 2008; Makris & Urgesi, 2015; Tomeo et al., 2013; Urgesi et al., 2012) we hypothesized that the timing of their action simulation representations may differ from that of novice individuals.

To test this hypothesis, basketball players were asked to perform an *identification task.* They were shown videos of free basketball throws, which displayed only the initial body kinematics (i.e., body cues) or only the ball trajectory (i.e., ball cues) and were occluded for a variable period. After the occlusion, participants were presented with a static frame (test pose) that was taken from a subsequent phase of the same video or of a video of a different free basketball throw, whose execution involved different body kinematics and ball trajectory. Crucially, the test pose could depict a movement phase that was earlier, congruent or later than that expected from the continuity of the action during the occlusion period. In this task, timing features are only implicitly encoded by participants because they are asked to report whether the test pose depicted the same free basketball throw of the occluded video or a different one, irrespective of temporal congruence. In a second task, the test pose was always taken from the same free throws video displayed before the occlusion but it was shifted in time to depict an action phase that was either earlier or later as compared to what expected from the natural course of the action during the occlusion period. In this task participants were asked to perform an *explicit timing task* by reporting whether the test pose presented after the temporal occlusion had been taken too far forward or too far backwards in time, in relation to the duration of the temporal occluder. This way, we aimed to evaluate both the timing of simulated actions (i.e., implicit timing task- identification task) and the action time estimation abilities (i.e., explicit timing task) in experts. Furthermore, the basketball players' performance in the two tasks was compared with that of a group of novices (i.e. non-athletes) as well as with that of a group of volleyball players, in order to disentangle the role of domain-specific expertise and general motor dexterity acquired through training in different sports.

There is mounting research evidence suggesting that action simulation is essential to perform accurate predictions of an ongoing action. Given the unique (superior) ability of athletes to perceive body kinematics and simulate observed actions in sport sequences that they are familiar with (e.g., Abernethy et al., 2008; Makris & Urgesi, 2015; Urgesi et al., 2012), we expected to detect higher accuracy results in basketball players for both tasks described above, whose execution requires an implicit or an explicit extrapolation of temporal information. Furthermore, based on the findings that expertise increases representational momentum effects (Blättler et al., 2010; 2011) we expected that experts discrimination of action congruency is higher when the test pose represents an action phase that is later as compared to the natural course of actions, thus reflecting heightened anticipatory simulation of actions. In a similar vein, they should show a comparable anticipatory bias in the estimation of action duration in the explicit timing task. While the athletes' motor and perceptual expertise are likely to affect the perception of both body kinematics and ball flight trajectory

(Urgesi et al., 2012), we expected to find stronger expertise effects on the motor simulation of body movements (Aglioti et al., 2008).

Materials and methods

Participants

The experimental sample consisted of twenty expert basketball players aged 16-30 years (mean=20.19 years, SD=3.04), twenty expert volleyball players aged 17-25 years (mean=22.05 years, SD=2.63) and twenty novices aged 19-24 years (mean=21.1 years, SD=1.62). No differences in age were detected between the participants' groups (one-way ANOVA, [F (2,45)=0.72, p=0.49, $\eta p2$=0.03]). Basketball players had 12.2 years (SD=1.9) of experience playing basketball and volleyball players had 12.1 years (SD=3.7) of experience playing volleyball, with no difference between the two groups [$t(38)=0.11$, $p=0.915$]. Novices had no experience playing any sport. The model used in the presented videos was a female. For this reason, we decided to test only female participants in order to match the gender of the observers and that of the model depicted in the videos and to better facilitate the involvement of simulation processes.

All the participants were right-handed according to a standard handedness inventory (Briggs & Nebes, 1975). All basketball and volleyball athletes played in amateur Italian League teams, while all novices reported no experience of having received training or playing sports. All participants reported normal or corrected-to-normal visual acuity in both eyes and were naïve to the purpose of the study. Informed consent was obtained from all participants and they were compensated for taking part. The experimental procedures were approved by the ethics committee of the Scientific Institute "E. Medea" and complied with the ethical standards of the Declaration of Helsinki (1964).

Stimuli and apparatus.

The videos of 2 types of basketball free-throws (A and B; see Fig. 1) were recorded by means of a digital video camera (JVC GYHM150U) mounted on a tripod and positioned laterally outside the 3-point line of a basketball field (Palasport Carnera of Udine, Italy). Four different replica of the same type of basketball free throw were recorded, with the same female player (aged 20 years) serving as model. As shown in Figure 1, the two throws were characterized by different body kinematics and ball trajectory along the whole duration of the action. Indeed, as compared to throw A, throw B had a more prominent parabolic trajectory of the ball, which was determined by pushing the ball on the vertical axis more than on the horizontal axis by keeping the shoulder, elbow and wrist articulations more flexed. The videos were edited with Adobe Premiere software to have the same 2,200-ms duration. In particular, from each selected video, we extracted a 1,650 ms sequence around the point when the hand-ball contact was broken, thus ensuring that the ball left the hand at 1,100 ms after each video onset, although the starting position of the model and the visible ball trajectory could slightly vary for the different videos (less than ± 100 ms).

Then, all videos were split into two video-clips at the 1,100 ms mark where hand-ball contact was broken. Each video-clip was then divided in 22 frames, each presented for 50 ms (i.e., 3 screen refresh rates), for a total duration of 1,100 ms. During the experiment, participants sat in a dimly light room, 80 cm away from a 19-inches CRT monitor (resolution, 1,024 × 768 pixels; refresh frequency, 60 Hz), on which video-clips were presented on a black background and subtended a 14.4° × 11.5° region. The experimental task was designed and run by E-Prime software, which also collected subjects' responses. Finally, we run the STATISTICA software for analyzing the acquired data. The stimuli were presented in two tasks, whose administration order was counterbalanced between subjects.

Figure 1 over here

Figure 1. The figures A and B depict the two different body kinematics (left panels) and ball trajectories (right panel) of the two types of basketball free throws. Please note that the more parabolic trajectory of the ball in throw B was determined by greater vertical pushing of the ball by keeping the shoulder, elbow and wrist angles more flexed.

Task 1: Identification task

Participants were presented with video-clips showing different body postures of professional basketball players (i.e., body cue) or video-clips showing different ball-trajectories following a shot (i.e., ball cue). In both cases, they were interrupted after a variable interval from the onset (i.e. Interruption time: 300 and 500 ms) and replaced by a mask occlusion of variable duration (Occlusion Time: 100, 300, 500 ms). Using variable Interruption and Occlusion times was aimed at ruling out participants could create expectations on event timing and predict the onset and offset of the occlusion, thus maximizing the possibility that participants were involved in an online simulation of the action course during the (unpredictable) occlusion period. Video interruption always occurred at the ascending phase of the ball trajectory and the occluded trajectory could include both the ascending and descending phase. Studies have shown that the extent of representational momentum is influenced by both velocity and gravity, with greater forward displacement for downward motion (see Hubbard et al., 2005 for a review). However, in the present study we did not systematically control or these variables, since the main aim was to study the effects of familiarity and motor expertise on the representation of body kinematics. After the occlusion a test pose was presented that depicted the frame of an action taken at different interval from the interruption time (Pose time: 100, 300, 500 ms). Thus, the combination of the longest Interruption time and longest Occlusion/Pose times was within the total duration of the video-clips. For each interruption time, the factorial combination of the Occlusion and Pose times (see Table 1) allowed having trials in which the test pose depicted a phase of the action that was too early, synchronous or too late in relation to the time elapsed between the interruption of the action and its subsequent continuation (Occlusion time). The difference emerging from the combination of the Pose Time and the Occlusion time will be called from now on Stimulus Onset Asynchrony (SOA, - 400 ms, - 200 ms, 0 ms, 200 ms, 400 ms), as it represents the amount of temporal incongruence between the phase of the internally simulated action and that depicted in the test pose (see table 1 for details).

Pose / **Occlusion**	**100 ms**	**300 ms**	**500 ms**
100 ms	Synchronous (0 ms)	Late (200 ms)	Late (400 ms)
300 ms	Early (-200 ms)	Synchronous (0 ms)	Late (200 ms)
500 ms	Early (- 400 ms)	Early (- 200 ms)	Synchronous (0 ms)

Table 1. The table summarizes the different SOAs emerging by subtracting the occlusion time from the pose time (early: -400 ms, -200 ms; synchronous: 0 ms; late: 200 ms, 400 ms)

The test pose was always taken from the body-cue phase after presentation of a body-cue video-clip and from a ball-trajectory phase after presentation of a ball-trajectory video-clip. In half of the trials, however, the test pose was taken from the same type of throw as compared to the one shown in the video-clip (same), while in the other half it was taken from a different type of throw having different body kinematics and ball trajectory (different). Table 2 illustrates the different possible combinations. With respect to the body cue condition, participants were asked to indicate if the body pose of the action frame presented after the temporal occlusion indicated the subsequent moment of the same body action presented before the temporal occlusion (rather than to an action with different body kinematics). With respect to the ball cue condition, participants were asked to indicate if the ball trajectory presented after the temporal occlusion followed the subsequent portion of the same ball trajectory illustrated in the frame preceding the temporal occlusion (rather than the trajectory belonging to a different throw). Subjects were responding by pressing one of the two mouse buttons (“left” for same, “right” for different). We did not instruct participant about the strategy to be used to perform the task, in order to avoid inducing bias in their response. Thus, any request of using simulation or extrapolation processes was left completely implicit. Overall, there were 384 trials, divided in 8 experimental blocks, with random presentation of same and different conditions, body- or ball-cue video-clips, Interruption times and SOAs.

Combination	START SHOOTING	OCCLUSION	TEST POSE
Congruent (same)	VIDEO A	Variable duration	VIDEO A
Congruent (same)	VIDEO B	Variable duration	VIDEO B
Incongruent (different)	VIDEO A	Variable duration	VIDEO B
Incongruent (different)	VIDEO B	Variable duration	VIDEO A

Table 2: Congruent and incongruent combinations of the two types of video-clips. All combinations were presented at early, synchronous, or later Occlusion-Pose time combinations.

Task 2: Explicit timing task

In this task, participants were asked to establish whether the actions presented after the temporal occlusion (i.e., body cue vs. ball cue) had been taken too far forward or too far backwards in time, in relation to the duration of the temporal occluder. The same stimuli of the identification task were used but the pre-occlusion video-clips and the test pose always depicted the same type of throw (same trials). Moreover, in keeping with standard procedure used in temporal estimation tasks (Fetterman, 2006, pp 290), only negative or positive SOAs were presented (i.e., the Pose time was never congruent with the Occlusion time). Participants were asked to indicate, by pressing the mouse buttons, whether the time at which the test pose was taken (Pose time) was too short or too long with regards to the occlusion duration. As for the identification task, no explicit instruction was given to the participants about the strategy to use to perform the task. In the event that the Pose time was shorter than the Occlusion time, the value of SOA would be negative and therefore would create an inconsistent anticipation with regards to the correct timing of the action (i.e., earlier SOA = -200 ms, - 400 ms). In the event that the Pose Time was greater than the Occlusion time, the value of SOA would be positive and therefore would create an inconsistent delay with regards to the correct timing of the action (i.e., later SOA= 200 ms, 400 ms). The different experimental conditions were presented in four 64-trials blocks for a total of 256 trials.

Results

Table 3 shows the mean accuracy values of the three groups of participants for the Identification and Explicit timing task. In keeping with the processing and response requirement of the two tasks, appropriate analyses were run in order to grasp how the sensitivity of the three groups in detecting difference between the kinematics/trajectory of the test pose was affected by the manipulation of the temporal synchrony between the stimuli (Identification task) and whether the three groups showed different bias in the temporal estimation of body actions and ball trajectory (Explicit timing task).

	Body Cue (Kinematics)			**Ball cue (Trajectory)**		
	Identification Task					
	Earlier SOAs (-400, -200 ms)	**Synchronous SOAs (0 ms)**	**Later SOAs (200, 400 ms)**	**Earlier SOAs (-400, -200 ms)**	**Synchronous SOAs (0 ms)**	**Later SOAs (200, 400 ms)**
Basketball player	79.57 ± 3.58%	64.7 ± 2.94%	46.5 ± 4.73%	66.87 ± 3.41%	55.05 ± 2.74%	53.9 ± 4.3%
Novices	72.4 ± 2.87%	59.25 ± 2.89%	45.7 ± 4.87%	53.2 ± 3.4%	50.9 ± 2.9%	52.75 ± 4.6%
Volleyball players	59.7 ± 2.85%	52.05 ± 2.94%	36.82 ± 4.88%	61.05 ± 3.41%	50.55 ± 2.9%	35.23 ± 4.25%
	Explicit Task					
Basketball player	78.95 ± 4.33%		93.65 ± 1.51%	78.45 ± 6.18%		96.55 ± 1.39%
Novices	72.88 ± 5.03%		89.05 ± 2.95%	81.58 ± 4.74%		90.48 ± 3.17%
Volleyball players	71.88 ± 3.59%		90.88 ± 2.56%	75.95 ± 4.78%		91.63 ± 3.34%

Table 3. Accuracy values for the two tasks. The table show the mean (± standard error of the mean) accuracy values of our three groups of participants for the Identification and the Explicit timing tasks for both the body cue and ball cue conditions. Note that while the Identification task included both synchronous and asynchronous (either early or late) conditions, the Explicit timing task included only asynchronous SOAs in order to avoid biases in timing estimation. Visual inspection of the values suggests that participants were more accurate in matching the test pose to the occluded action videos at Earlier and Synchronous SOAs, but they tended to commit more timing estimation errors for earlier than later SOAs. This means that they judged that the time at which the test pose was taken was too long as compared to the occlusion duration even when the actual pose time was too short (i.e., early SOAs).

Task 1: Identification task, Considering that in two-alternative-forced-choice tasks, like the one in the present study, it is possible that accuracy percentage conflates bias with decision, we used a standard adaptation of the SDT to 2-

alternative forced choice tasks (Macmillan & Kaplan, 1985). Thus, we calculated and analysed d' prime and criterion (c) by plotting the proportion of same responses in same and different trials. The d' prime and lnβ scores were then calculated, considering as "hits" same responses for the same trials and as "false alarms" same responses for the different trials. The *d'* values were calculated by transforming the response proportion to z-scores, and then subtracting the z-score corresponding to the hit rate from the z-score corresponding to the false-alarm rate (Stanislaw and Todorov, 1999). Hence, the higher the *d-prime* score, the better participants were able to detect a discrepancy in the kinematic patterns of the different test pose sequences. Furthermore, we calculated, for each subject and condition, a measure of response criterion (c), which reflects the existence of a bias in providing a specific response. The *c* values were calculated by averaging the z-score corresponding to the hit rate and the z-score corresponding to the false alarm rate, and then multiplying the result by -0.5 (Stanislaw and Todorov, 1999).

Data were then added in mixed-model Analysis of Variance (ANOVA) with type of occluded cue (i.e., body cue, ball cue) and SOA (i.e., early, synchronous, late) as within-subjects variable and expertise group (i.e., basketball players, volleyball players and novices) as between-subjects factors. The two interruption times (300 ms, 500 ms) as well as the two negative (-400 ms and -200 ms) and the two positive (200 ms and 400 ms) SOAs were collapsed in order to analyze the same number of trials for early, synchronous and late SOA conditions (64 trials per cell).

d-prime analysis: The results revealed a significant main effect of cue type [$F(1, 57)=10.19$, $p=0.002$, $\eta^2=0.151$] a significant main effect of SOA [$F(2, 114)=88.44$, $p<0.001$, $\eta^2=0.608$], and a significant main effect of group [$F(2, 57)=7.95$, $p<0.001$, $\eta^2=0.218$]. We also detected a trend for a significant cue type x group interaction [$F(2, 57)=3.06$, $p=0.054$, $\eta^2=0.097$]. On the other hand, there were significant group x SOA [$F(4, 114)= 7.71$, $p<0.001$, $\eta^2=0.212$] and cue type x SOA [$F(2, 114)=10.35$, $p<0.001$, $\eta^2=0.153$] interactions. Finally, we detected a significant interaction between cue type, SOA, and group [$F(4, 114)=5.22$, $p<0.001$, $\eta^2=0.154$]. Newman-Keuls post-hoc comparisons revealed a significant difference for the body-cue stimuli only. In particular, basketball players' d-prime scores for the earlier SOAs were higher ($M=2.08 \pm 0.233$ SE) as compared to those for novices ($M=1.26 \pm 0.233$ SE, $p<0.001$) and volleyball players ($M=0.563 \pm 0.233$ SE, $p<0.001$). In contrast, no difference was detected comparing novices to volleyball players ($p=0.124$). We also found a significant difference in the synchronous SOA by comparing basketball players' performance ($M=1.23 \pm 0.138$ SE) to that of volleyball players ($M=0.34 \pm 0.138$ SE, $p=0.0207$), but not to that of novices ($M=0.85 \pm 0.138$ SE, $p=0.274$). In a similar fashion, no difference was found comparing novices to volleyball players ($p=0.508$). Finally, there were no significant differences detected for the later SOAs between the three groups (Figure 3). Considering the differences across SOAs within each group, we found a significant decrease of performance in matching body kinematics with longer SOAs in the groups of basketball players (all $p<0.001$) and novices (all $p<0.03$), while only the difference between the early and later SOAs was significant in volleyball players (p=0.044). Basketball players' performance in matching the ball trajectory was also higher for the earlier than synchronous (p= 0.013) and later (p<0.001) SOAs, which in turn did not differ (p=0.206). No difference between SOAs was observed for the ball cue in novices, while again only the difference between the early and later SOAs was significant in volleyball players (p=0.002). All other between-SOAs comparisons were non significant (p>0.07).

These data were further corroborated by testing whether performance of the three groups was different than chance in the various conditions by using single-sample t-test (two-tailed) to compare d' values against 0. The results of this analysis revealed that the d' values of basketball players were significantly higher than 0 in all conditions [all $t(19)>2.6$, $p<0.015$)] except for the later SOAs of the body-cue trials [$t(19)=1.49$, $p=0.154$]. Conversely the d' values of novices were different than 0 in all conditions [$t(19)>2.8$, $p<0.012$], while the d' values of volleyball players for both the body and ball cues were significantly different than 0 at the early [all $t(19)>2.99$, $p<0.08$)] and synchronous [all $t(19)>3.3$, $p<0.004$)] SOAs, but not at the later SOAs [all $-0.1<t(19)<1.1$, $p>0.296$)]. Overall, these data shows that performance of all groups decreased with increasing SOAs, but the effect was stronger and more consistent for domain-specific experts.

Figure 2 over here

Figure 2. Action identification task performance. *D-prime score.* Results show higher d-prime scores for the basketball players group compared to volleyball players and novices in the earlier SOA of the body cue condition. Moreover, basketball players' d-prime scores are higher than those of the volleyball group in the synchronous SOA of the body cue condition. Vertical bars indicate standard error of the mean. Likewise, we did not detect significant differences for the ball cue condition in any group (See figure 3 and table 2 for a summary of average scores).

criterion analysis: . The results have indicated a significant main effect of SOA [$F(2, 114)=3.79$, $p=0.025$, $\eta^2=0.062$], with larger criterion for later SOAs. In contrast, no significant results were detected for cue type [$F(1, 57)=0.338$, $p<0.562$, $\eta^2=0.005$], group [$F(2, 57)=0.105$, $p<0.899$, $\eta^2=0.003$], and for the type x SOA [$F(2, 114)=2.77$, $p<0.066$, $\eta^2=0.046$], cue type x group [$F(2, 57)=0.988$, $p=0.378$, $\eta^2=0.033$], group x SOA [$F(4, 114)=1.165$, $p<0.329$, $\eta^2=0.039$] and cue x group x SOA [$F(4, 114)=1.301$, $p<0.273$, $\eta^2=0.043$] interactions. See figure 4 for further details.

Figure 2 over here

Figure 3. Identification task performance. *Criterion score.* Results document no between groups difference for both body and ball cues with respect to the three examined SOAs. Vertical bars indicate standard error of the mean.

Task 2: Explicit timing task

A psychophysics analysis (Point of Subjective Equality, PSE) was performed on accuracy data acquired from the explicit task for the three groups of participants. This is the standard data analysis procedure expected for tasks requiring a binary response pattern that allows estimating at which point the difference between two durations is detectable. In our case, at the PSE, the subject perceives the pose time and the occluder time to be the same. In particular, PSEs were obtained by fitting proportion of "too long" responses as a function of SOA with a logistic function. PSEs were then entered in a 3 x 2 mixed model ANOVA, with group (Basketball players, Novices, Volleyball players) as between-subjects factor and type of cue (body cue, ball cue) as within-subjects variable. The results indicated a significant main effect of cue type [$F(1, 57)=103.74$, $p<0.001$, $\eta^2=0.645$]. This analysis showed a general tendency to overestimate temporal durations in the ball cue task, as compared to the body cue task (See figure 5). In contrast, the group factor was not significant [$F(2, 57)=0.09$, $p<0.906$, $\eta^2=0.003$]. Finally, the group x type of cue factor interaction was significant [$F(2, 57)=3.42$, $p<0.039$, $\eta^2=0.107$. See figure 4 for details]. However, no significant between groups differences were detected for either type of cues ($p> 0.50$). Indeed, using one-sample t test (two-tailed) to test if PSEs for each cue and group were different than 0, we found that the PSE for the ball cue was lower than 0 in all groups (Basketball players: $t(19)=-4.37$, $p<0.001$; Novices: $t(19)=-5.07$, $p<0.001$; Volleyball players; $t(19)=-5.74$, $p<0.001$); conversely, the PSE for the body cue task was not different than 0 (no bias) in any group (Basketball players: $t(19)=-1.19$, $p=0.248$, Novices: $t(19)=-0.25$, $p=0.806$; Volleyball players: $t(19)=-0.76$, $p=0.457$).

Figure 4 over here

Figure 4. Point of subjective equality (PSE). The figure shows the PSE (expressed in msec) of the three groups of participants with respect to both Body cue (i.e., kinematics) and ball cue (i.e., trajectory) conditions. Results document a significant group x type of cue interaction term. In particular, it was reported an overestimate of temporal durations (i.e. lower PSE) of the ball trajectories (i.e., from ball cues), compared to the body kinematics (i.e., from body cues).

Discussion

Accurate temporal estimations are essential to program and execute everyday activities (Vicario et al., 2011, 2012). In sport, accurate timing skills might prove critical for a competitive and successful performance, given their key role in movement coordination/synchronization and action anticipation.

In the present study we investigated the ability of a group of professional basketball players to make implicit (i.e., establishing whether the body posture or ball trajectory displayed after a variable period of occlusion belonged to the action preceding that occlusion- identification task) and explicit (i.e., establishing whether the actions previously mentioned - i.e., body cue vs. ball cue - presented after the temporal occlusion, had been taken too far forward or too far backwards in time, in relation to the duration of the occluder) temporal estimations. To test the role of familiarity and previous motor experience in accurate temporal predictions for action sequences the basketball players' performance was compared to that of professional volleyball players and novices.

Identification task

It has been previously documented that the ability to determine whether the final part of an action sequence belonged (or not) to the same action interrupted by an occluder is mediated by implicit timing skills, as this comparison requires the temporal predictability of perceptual input (Coull & Nobre, 2008).

Here we found that basketball players were more accurate, as compared to both control groups, in establishing the compatibility/incompatibility between the presented body kinematic frames. In particular, we demonstrated that this difference was significant for earlier SOAs. Moreover, we found higher response accuracy in basketball players, as compared to expert volleyball athletes for the synchronous SOAs. In contrast, no significant between-groups difference was detected for the later SOAs. Finally, there was no between group difference for the ball trajectory conditions. Interestingly, overall earlier SOAs led to better performance than later SOAs in all groups, and in particular in basketball players, suggesting that participants found it easier to match action kinematics when the pose depicted a phase of the action that was delayed as compared to what was expected to occur during the occlusion period. Since better accuracy in this task seems to derive from the correspondence between the state of the simulation process and the phase of the action depicted in the test pose (Springer et al., 2013), these results may suggest that simulated actions were slower as compared to the external counterpart.

This result is in partial contrast with the findings of studies using the occluder paradigm to test the timing of action simulation processes (Springer et al., 2013). For example, in one of these studies (Springer et al., 2011) point light action sequences were interrupted by an occluder followed by a test pose. Participants were required to indicate whether the test pose depicted a continuation of the occluded action and it was found that response accuracy was reduced with an increased time distance between the duration of the occlusion and the pose time, independently from the direction of the difference. The authors suggested that this is direct evidence of an internal simulation of observed actions that can mediate the accurate prediction of action outcomes and has similar temporal features than external actions. Crucially, however, in a further study (Sparenberg et al., 2012) specifically aimed at testing the timing of action simulation, the authors found evidence of better performance for negative than positive SOAs, thus suggesting that simulated action were slower than the time course of external actions. Overall, it has been shown that changing the task administered to the participants (Parkinson et al., 2011), the amount of visual information provided (Parkinson et al., 2012), the type of actions (Sparenberg et al., 2012) and the viewing perspective (Brattan et al., 2015) may affect the timing of action simulation (Springer et al., 2013). In the present study we show that presenting both experts and non-expert individuals with a complex action kinematics matching task, performance is improved when the test pose is delayed as compared to the time course of the external action and the participants are requested to match the spatial properties of action kinematics, thus pointing to slower action simulation. In keeping with previous studies using the occluder paradigm (Springer et al., 2013), finding better performance in all groups, and especially in domain-specific experts, for early than for synchronous and late SOAs would suggest that the action identification task required slowing down the temporal course of action simulation in order to have a more detailed description of the kinematics features of the movements. This may refine the ability to discriminate the subtle kinematics incongruence between two actions, especially when the task at handle is particularly complex. Thus, the complexity of the action identification task may explain differences between the timing of action simulation obtained in different studies and why we found a tendency for slower action simulation in the present study.

Action simulation processes may be modulated by action familiarity and previous motor experience with the observed actions (Abernethy & Zawi, 2007; Abernethy et al., 2008; Aglioti et al., 2008; Calvo-Merino et al., 2010; 2005; Cross et al., 2009; Urgesi et al., 2012). In keeping with this view, in the present study, expert basketball players made more accurate predictions as compared to non-experts individuals as well as to experts in different sports. This, however, was true for the early SOAs but not at the later ones, suggesting that the refined abilities of motor experts were particularly evident when the test pose depicted an early phase of the action as compared to what would be expected from its natural deployment. This might reflect that experts can slow down the simulation of actions to obtain a more refined prediction of their course. Furthermore, a slow-motion simulation might also serve to be ready to react to sudden changes of others' people direction of motion (Munger & Minchew, 2002), which can be used, for example, during deceptive behaviors (see also Makris & Urgesi., 2015; Tomeo et al., 2013). This slow-motion representation of familiar actions might, thus, endow experts with the ability to represent more details of invisible, occluded, or upcoming actions, thus allowing them to make more accurate predictions about ongoing actions. This ability might represent the key element for predicting the action outcome of both team mates and opponents, which is essential for successful performance in sports.

Another alternative explanation for the current result is that experts might be particularly able in predicting the timing of a familiar action just after the occlusion. Indeed, it is possible that perceptual comparison between the last posture displayed in the video-clip before the occlusion and the test pose might be facilitated when these represent a closer action phase (i.e., lower pose time) as compared to when they are more separated in time. Since manipulation of SOAs also induced a bias for lower pose times in the earlier SOAs, we cannot rule out that the reported effects might be, at least partially, explained by the use of a perceptual comparison strategy. However, such perceptual strategy could be used for both body and ball cues. Thus, the selectivity of the SOAs and group effects for the discrimination of body cues but not for the discrimination of ball cues makes it unlikely that the use of a purely perceptual strategy can be the only explanation of the results.

A further possible interpretation of the finding is that the decreased performance for later SOAs might reflect he existence of constant time error in simulation processes that might be due to the shift from a perceptual representation of the action and its internal simulation (Sparenberg et al., 2012; Springer et al., 2013). Indeed, Sparenberg et al., (2012) showed that the time at which action simulation hold behind the expected course of true motion was comparable across occlusion durations, thus suggesting that action simulation was not slowed down, otherwise the time error would increase with longer time of simulation. Conversely, these data suggest that the delay in action simulation was due to a constant process, which has been attributed to the switch between perception and simulation. Our manipulation of SOAs by varying both the occluder and pose times prevents us from testing the source of the delay in action simulation, and future studies that systematically manipulate the occluder times with standard pose times might help addressing this issue.

The findings of the present study might reveal overall higher performance abilities of basketball players as compared to that of controls, further indicating the roles of action familiarity and motor experience in making accurate predictions for action outcomes. This suggests that familiarity with the presented sportive actions serves a key role in making temporal predictions. In fact, we only detected higher response accuracy levels in basketball players viewing basketball free throws, while there was no significant difference comparing the performances of volleyball players and novices. Therefore, it may be that general sportive training, per se, has a minor role in the execution of such a task, in the absence of familiarity/expertise with the presented action sequences. However, this hypothesis remains speculative, as we did not test participants (i.e., arbiters) highly familiar with the presented actions in the absence of sport training. Nevertheless, the evidence of a better performance in detecting the compatibility of two body kinematics, but not ball trajectory, suggests that the reported results might be mediated by embodiment processes, which might have been refined by sportive training, rather than by higher perceptual sensitivity (Urgesi et al., 2012).

Explicit timing task

Focusing on participants' performance in the explicit timing task (i.e., establishing whether the actions presented after the temporal occlusion, had been taken too far forward or too far backwards in time in relation to the duration of the temporal occluder), we found overall negative PSE in all groups of participants, suggesting, again, that the timing of simulated actions was slower than that of external ones. This is in keeping with the results of (Sparenberg et al., 2012), who presented point-light displays of whole body actions and found a similarly negative PSE, but in contrast with those of (Brattan et al., 2015) who displayed hand movements and found a positive PSE, pointing to accelerated action simulation processes. Again, these findings suggest that the type of action and task may influence the timing of simulation processes.

This view is in keeping with studies (Finke & Shyi, 1988; Munger & Minchew, 2002) testing the effects of implied object weight and velocity on the timing distortions of memory of the last seen position of a moving object (i.e., representational momentum) and the prediction of its future position if the physical event was naturally continued during the retention interval. Indeed, while the remembered final position of a moving object is distorted forward along its motion path, it undershoots the position expected from its natural deployment (Finke & Freyd, 1985). In a similar vein, when observers are explicitly required to extrapolate the future position of the object, their prediction is behind its natural course of motion (Finke & Shyi, 1988). This suggests that both the representational momentum effect and the delayed prediction of the future position of objects are related to a mental extrapolation process that anticipates the continuation of occluded motion, but is slower as compared to the natural trajectory of the movement, a finding that reconciles the present results with the anticipatory bias obtained in representational momentum tasks. Crucially, the size of the backward distortion in the prediction task increases with the increasing load of the representation due, for example, to increased velocity or unnatural motion direction (Munger & Minchew, 2002). These findings might suggest that slower action simulation might reflect the increased load of the representation, which might be higher for the ball trajectory than for body movements in all groups.

Interestingly, we found for all three groups of participants slower simulation (i.e., lower PSE) of the ball trajectory than for the body cue stimuli, thus suggesting more precise temporal prediction for bodily actions than object movements. Furthermore, a significant overestimation of time was observed only when judging the ball trajectory, in keeping with the backward distortion observed in the extrapolation of the future position of moving objects (Finke &

Shyi, 1988; Munger & Minchew, 2002), but not while judging the body movements. However, no significant between groups differences were detected for both cue type conditions, thus suggesting that familiarity with domain-specific actions does not alter explicit temporal representations of actions and their consequences. Nevertheless previous studies (Blättler et al., 2010; 2011) have shown expertise effects for the anticipatory representation of visual stimuli (e.g., scenes), suggesting that previous perceptual experience modulates the extent at which the observers' can anticipate the trajectory of a visual stimulus. These studies, however, have used the representational momentum paradigm, which requires participants to remember the final position of an occluded object; thus, it does not involve the active simulation processes that have been called into action in the occluder paradigm (Springer et al., 2013). Our results for the ball cue videos, indeed, are in keeping with the finding (Blättler et al., 2010) that both experts and non-experts display representational momentum for moving objects, albeit expertise can modulate its amount.

Conclusion

Summarizing, in the present study we showed that professional athletes are provided with an altered implicit timing ability, which appears to be strictly related to their familiarity with the presented sportive actions and specific for body cues. In particular, we found that expert players are more accurate in determining if the final part of a sportive action sequence (i.e., body kinematic) belonged to the same body kinematic interrupted by the occluder, especially when the presented action frames corresponded to an earlier and synchronous outcome. This result mainly point to slow-motion bias of the action simulation abilities of expert players, which may allow them to represent actions in more fine-grained details and predict domain-specific actions with greater accuracy. This ability is not related to general sports expertise, since it was not observed in volleyball players for basketball actions. By contrast, no significant results were reported in the explicit timing task. This difference in the performance between the implicit (i.e., identification task) and the explicit timing tasks might be explained by assuming that these two tasks require different skills to be performed, as they are qualitatively different. In particular, one could observe that basketball players were more accurate in the identification task of body kinematics (i.e., body cues stimuli), as this task might require the activation of motor programs that are probably better processed by this group of participants, due to their higher familiarity with the presented stimuli. By contrast, the explicit timing task adopted in the current study mainly refers to visuo-perceptual skills and requires accurate temporal estimations, which might not differ among the different groups of participants. Thus, the dissociation between the two tasks might suggest that domain-specific expertise influences the accuracy and timing of internal simulation in discriminating subtle kinematics difference, but it does not introduce any bias in time estimation.

A limit of the current research, which can be addressed in further works, refers to the absence of a volleyball video-clips as additional condition. In fact, this would have provided a further test for the familiarity hypothesis discussed in the current research. Thus, future studies are required to establish i) whether the reported result in the discrimination task of body cues merely reflect the experts' simulation slow-motion bias, rather than another phenomenon; ii) and whether the reported effect is due to physical practice or perceptual familiarity or to a combination of the two (Calvo-Merino et al., 2006; Urgesi et al., 2012).

References

Abernethy B., Zawi, K., & Jackson, R.C. (2008). Expertise and attunement to kinematic constraints. Perception, 37, 931-48.

Abernethy, B. & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. Journal of Motor Behavior, 39, 353–67.

Aglioti, S.M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. Nature Neuroscience, 11, 1109-16.

Barr, K., & Hall, C. (1992). The use of imagery by rowers. International Journal of Sport Psychology, 23, 243–261.

Blättler, C., Ferrari, V., Didierjean, A., van Elslande, P., & Marmèche, E. (2010). Can expertise modulate representational momentum? Visual Cognition, 18(9), 1253–73.

Blättler, C., Ferrari, V., Didierjean, A., & Marmèche, E. (2011). Representational momentum in aviation. Journal of Experimental Psychology: Human Perception and Performance, 37(5), 1569–77.

Brattan, V.C., Baker, D.H., & Tipper, S.P. (2015). Spatiotemporal Judgments of Observed Actions: Contrasts Between First- and Third-Person Perspectives After Motor Priming Journal of Experimental Psychology Human Perception and Performance, 41, 1236–1246.

Briggs, G.G., & Nebes, R.D. (1975). Patterns of hand preference in a student population. Cortex, 11, 230-8.

Calvo-Merino, B., Ehrenberg, S., Leung, D., & Haggard, P. (2010). Experts see it all: Configural effects in action observation. Psychological Research, 74, 400–6.

Calvo-Merino, B., Glaser, D.E., Grèzes, J., Passingham, R.E., & Haggard, P. (2005). Action observation and acquired motor skills: an FMRI study with expert dancers. Cerebral Cortex, 15, 1243–9.

Calvo-Merino, B., Grèzes, J., Glaser, D.E., Passingham, R.E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. Current Biology, 16, 1905–10.

Chen, Y.H., Pizzolato, F., & Cesari, P. (2014). Time flies when we view a sport action. Experimental Brain Research, 232, 629-35.

525 Cross, E.S., Kraemer, D.J.M., De, A.F. Hamilton, A., Kelley, W.M., & Grafton, S.T. (2009). Sensitivity of the action observation network to physical and observational learning. Cerebral Cortex, 19, 315–26.

527 Coull, J., & Nobre, A. (2008). Dissociating explicit timing from temporal expectation with fMRI. Current Opinion in Neurobiology, 18, 137-44.

529 Denis, M., Chevalier, N., & Eloi, S. (1985). Visual imagery and the use of mental practice in the development of motor skills. Canadian Journal of Applied Sport Sciences, 10(Suppl.), 4S–16SI.

531 Fetterman, J.G. (2006). Time and number: learning, psychophysics, stimulus control, and retention. Comparative Cognition. Experimental Explorations of Animal Intelligence (ed. Edward A Wasserman and Thomas R Zentall) Oxford University Press, pp 290.

534 Finke, R.A., & Freyd, J.J. (1985). Transformations of visual memory induced by implied motions of pattern elements. Journal of Experimental Psychology: Learning Memory and Cognition, 11, 780-794.

536 Finke, R.A., & Shyi, G.C. (1988). Mental extrapolation and representational momentum for complex implied motions. Journal of Experimental Psychology Learning Memory and Cognition, 14, 112-120.

538 Flach, R., Knoblich, G., & Prinz, W. (2004). The two-thirds power law in motion perception. Visual Cognition, 11, 461-481.

540 Freyd, J.J. (1983). The mental representation of movement when static stimuli are viewed. Perception and Psychophysics, 33, 575-581.

542 Freyd, J.J., & Finke, R.A. (1984). Facilitation of length discrimination using real and imaged context frames. American Journal of Psychology, 97(3), 323-41

544 Graf, M., Reitzner, B., Corves, C., Casile, A., Giese, M., & Prinz, W. (2007). Predicting point-light actions in real-time. Neuroimage, 36, T22–T32.

546 Guillot, A., & Collet, C. (2005). Duration of mentally simulated movement: a review. Journal of Motor Behavior, 37(1), 10-20.

548 Hubbard, T.L. (2005). Representational momentum and related displacements in spatial memory: A review of the findings. Psychonomics Bullettin & Review, 12(5), 822-51

550 Kerzel, D. (2006). Why eye movements and perceptual factors have to be controlled in studies on "representational momentum". Psychonomics Bullettin & Review, 13(1), 166-73;

552 McIntyre, T., & Moran, A. (1996). Imagery validation: How do we know athletes are imaging during mental practice. Journal of Applied Sport Psychology, 8, S132

554 Macmillan, N.A., & Kaplan, H.L. (1985) Detection theory analysis of group data: estimating sensitivity from average hit and false-alarm rates. Psychological Bullettin, 98(1), 185-99.

Makris, S. & Urgesi, C. (2015). Neural underpinnings of superior action prediction abilities in soccer players. Social Cognitive Affective Neuroscience, 10, 342-51.

Motes, M.A., Hubbard, T.L., Courtney, J.R., & Rypma, B. (2008). A principal components analysis of dynamic spatial memory biases. Journal of Experimental Psychology: Learning Memory and Cognition, 34, 1076-1083.

Munger, M. P., & Minchew, J. H. (2002). Parallels between remembering and predicting an object's location. Visual Cognition, 9(1-2), 177–194.

Munger, M., & Owens, T. R. (2004). Representational momentum and the flash‐ lag effect. Visual Cognition, 11(1), 81–103.

Nather, F.C., Bueno, J.L., Bigand, E., & Droit-Volet, S. (2011). Time changes with the embodiment of another's body posture. PLoS One, 6, e19818.

Oishi, K., Kasai, T., & Maeshima, T. (2000). Autonomic response specificity during motor imagery. Journal of Physiology and Anthropology and Applied Human Science, 19, 255–261

Palmer, C., Koopmans, E., Loehr, J.D., & Carter, C. (2009). Movement-related feedback and temporal accuracy in clarinet performance. Music Perception, 26, 439-449.

Parkinson, J., Springer, A., & Prinz, W. (2011). Can you see me in the snow? Action simulation aids the detection of visually degraded human motion. The Quarterly Journal of Experimental Psychology, 64, 1463–72.

Parkinson, J., Springer, A., & Prinz, W. (2012). Before, during and after you disappear: Aspects of timing and dynamic updating of the real-time action simulation of human motions. Psychological Research, 76, 421–433.

Ramnani, N., & Miall, R.C. (2004). A system in the human brain for predicting the actions of others. Nature Neuroscience, 7, 85-90.

Sparenberg, P., Springer, A., & Prinz, W., (2012). Predicting others' actions: evidence for a constant time delay in action simulation. Psychological Research, 76, 41–9, 2012

Springer, A., Brandstädter, S., Liepelt, R., Birngruber, T., Giese, M., Mechsner, F., et al. (2011). Motor execution affects action prediction. Brain and Cognition, 76, 26–36.

Springer, A., Parkinson, J., & Prinz, W. (2013). Action simulation: time course and representational mechanisms. Frontiers in Psychology, 4, 1–20.

Stadler, W., Springer, A., Parkinson, J. & Prinz, W. (2012). Movement kinematics affect action prediction: comparing human to non-human point-light actions. Psychological Research, 76, 395–406.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. Behavior Research Methods Instruments Computers 31(1), 137-49.

Tomeo, E., Cesari, P., Aglioti, S.M., & Urgesi, C. (2013). Fooling the kickers but not the goalkeepers: behavioral and neurophysiological correlates of fake action detection in soccer. Cerebral Cortex, 23, 2765-78.

Urgesi, C., Maieron, M., Avenanti, A., Tidoni, E., Fabbro, F., & Aglioti, S. M. (2010). Simulating the future of actions in the human corticospinal system. Cerebral Cortex, 20(11), 2511–21.

Urgesi, C., Savonitto, M.M., Fabbro, F., & Aglioti, S.M. (2012). Long- and short-term plastic modelling of action prediction abilities in volleyball. Psychological Research, 76, 542-60.

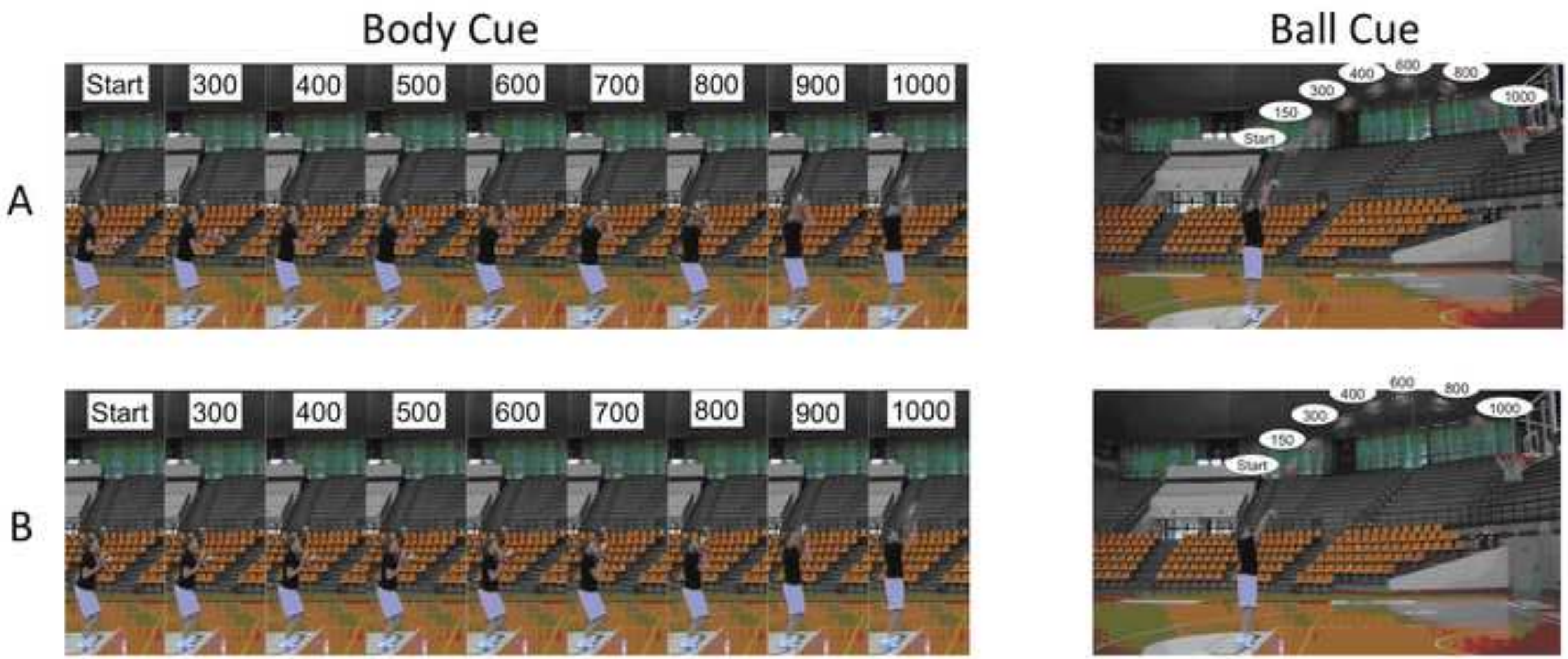
Verfaillie, K., & Daems, A. (2002). Representing and anticipating human actions in vision. Visual Cognition, 9,217 - 232.

Vicario, C. M., Martino, D., Pavone, E.F., & Fuggetta, G. (2011). Lateral head turning affects temporal memory. Perceptual and Motor Skills, 113, 3-10.

Vicario, C.M., Bonní, S., & Koch, G. (2011). Left hand dominance affects supra-second time processing. Frontiers in Integrative Neuroscience, 5, 65.

Vicario, C.M., Martino, D., & Koch, G. (2013). Temporal accuracy and variability in the left and right posterior parietal cortex. Neuroscience, 245, 121-8, 2013

Zago, M., & Lacquaniti, F. (2005). Visual perception and interception of falling objects: a review of evidence for an internal model of gravity. Journal of Neural Engineering, 2, S198-S208.


Body Cue
Ball Cue
A
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Start
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Figure 2

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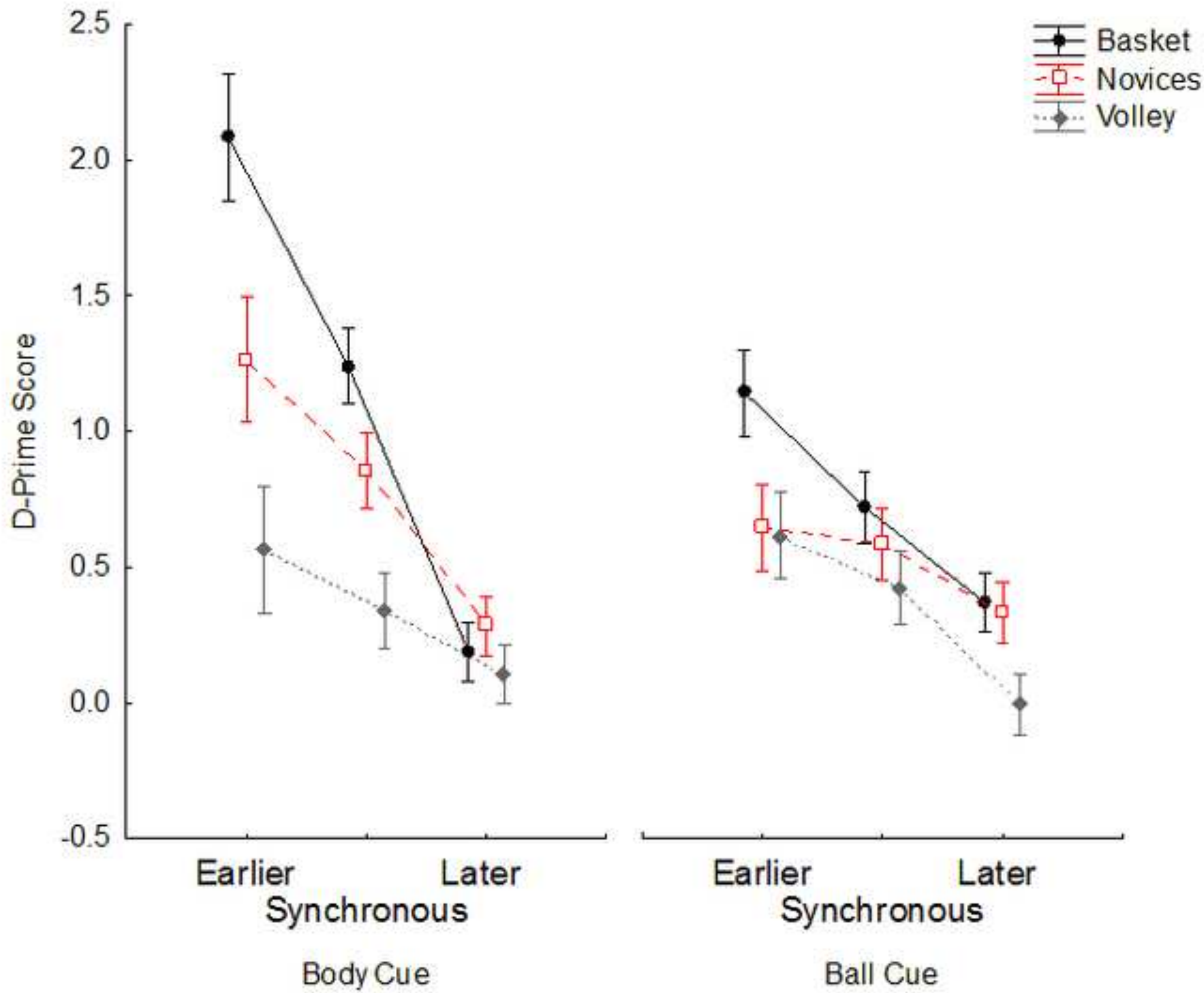
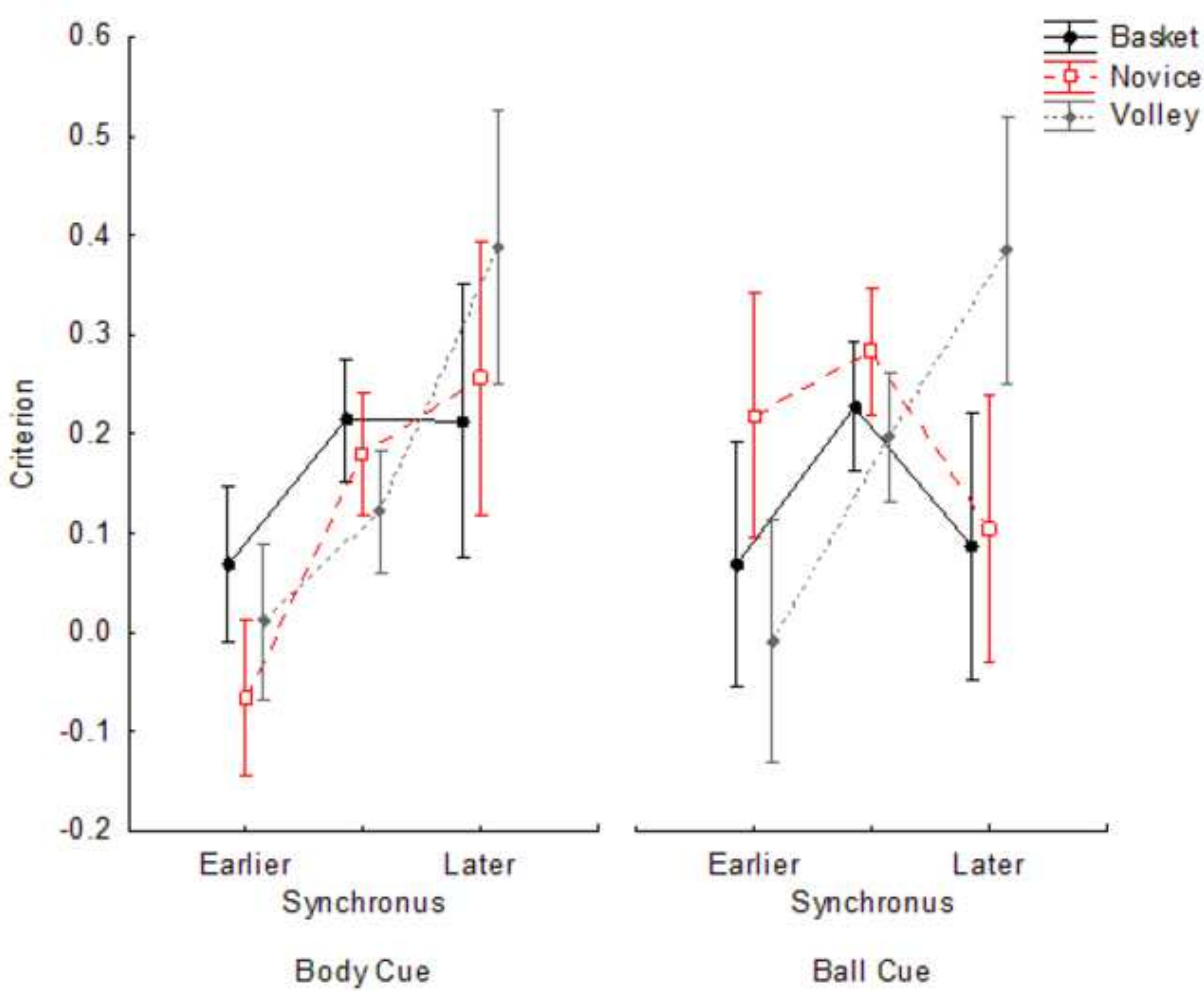


Figure 3



Basket
Novice
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Ball Cue

Figure 4 Click here to download Figure Figure 4.TIF

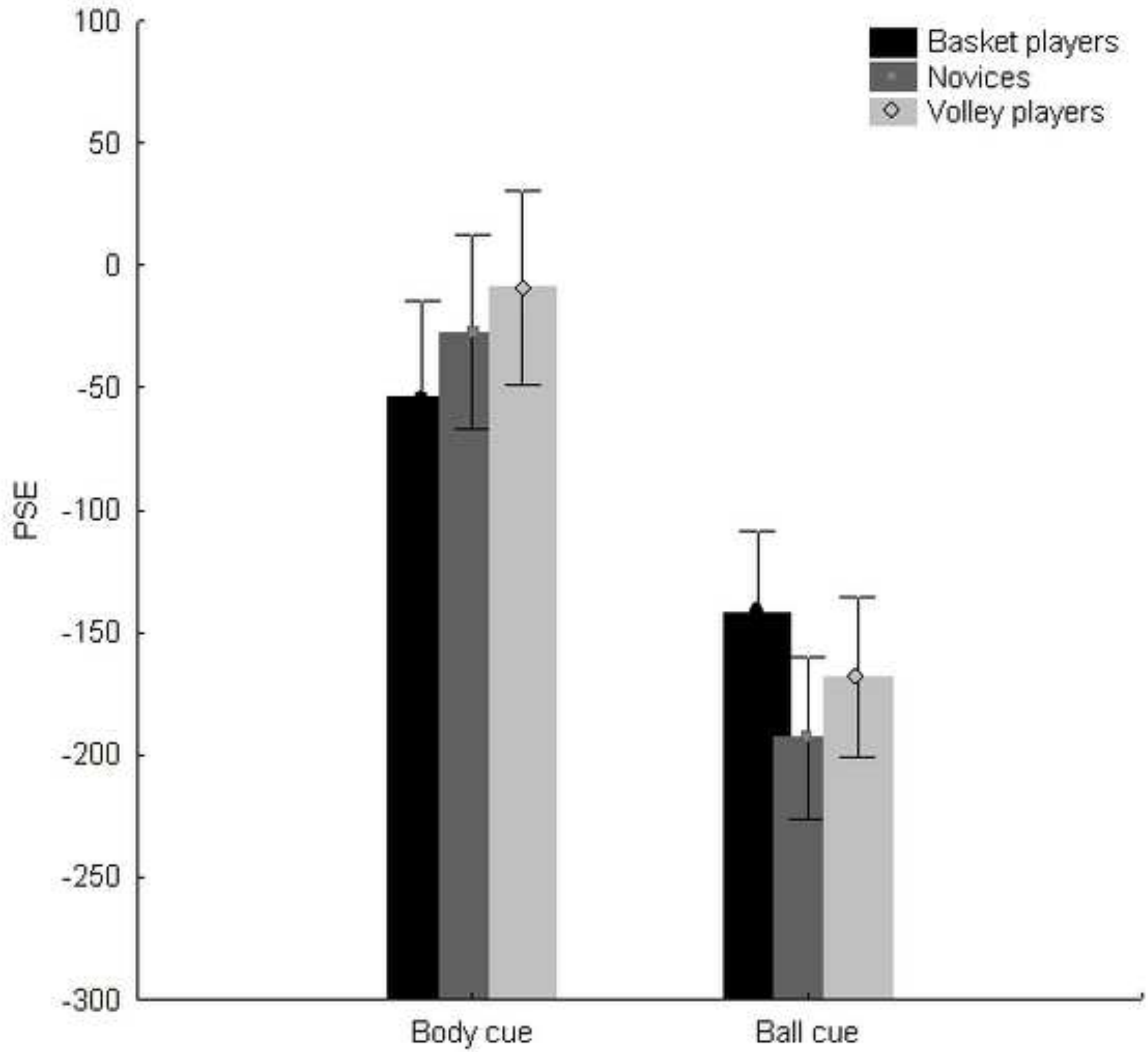

Table 1

Pose **Occlusion**	**100 ms**	**300 ms**	**500 ms**
100 ms	Synchronous (0 ms)	Late (200 ms)	Late (400 ms)
300 ms	Early (-200 ms)	Synchronous (0 ms)	Late (200 ms)
500 ms	Early (- 400 ms)	Early (- 200 ms)	Synchronous (0 ms)

Table 2

Combination	**START SHOOTING**	**OCCLUSION**	**TEST POSE**
Congruent (same)	VIDEO A	Variable duration	VIDEO A
Congruent (same)	VIDEO B	Variable duration	VIDEO B
Incongruent (different)	VIDEO A	Variable duration	VIDEO B
Incongruent (different)	VIDEO B	Variable duration	VIDEO A

Table 3

	Body Cue (Kinematics)			Ball cue (Trajectory)		
	Identification Task					
	Earlier SOAs (-400, -200 ms)	**Synchronous SOAs (0 ms)**	**Later SOAs (200, 400 ms)**	**Earlier SOAs (-400, -200 ms)**	**Synchronous SOAs (0 ms)**	**Later SOAs (200, 400 ms)**
Basketball player	79.57 ± 3.58%	64.7 ± 2.94%	46.5 ± 4.73%	66.87 ± 3.41%	55.05 ± 2.74%	53.9 ± 4.3%
Novices	72.4 ± 2.87%	59.25 ± 2.89%	45.7 ± 4.87%	53.2 ± 3.4%	50.9 ± 2.9%	52.75 ± 4.6%
Volleyball players	59.7 ± 2.85%	52.05 ± 2.94%	36.82 ± 4.88%	61.05 ± 3.41%	50.55 ± 2.9%	35.23 ± 4.25%
	Explicit Task					
Basketball player	78.95 ± 4.33%		93.65 ± 1.51%	78.45 ± 6.18%		96.55 ± 1.39%
Novices	72.88 ± 5.03%		89.05 ± 2.95%	81.58 ± 4.74%		90.48 ± 3.17%
Volleyball players	71.88 ± 3.59%		90.88 ± 2.56%	75.95 ± 4.78%		91.63 ± 3.34%